

NUMERICAL SIMULATIONS OF LARGE DEFORMATION CABLE DYNAMICS

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Cable systems are used in diverse applications, for which it is important to know the shape of the cable as time evolves. The objective of this research is to accurately predict the geometry of a cable subjected to aerodynamic or hydrodynamic forces in both high- and low-tension applications.

A one-dimensional elastic continuum model for describing the nonlinear dynamic loop formation in cables is developed. The model accounts for the cable tension, two-axis bending, torsion, weight, buoyancy, fluid drag, and fluid inertia. The three-dimensional equations of motion of the cable are developed first using Euler angles and then Euler parameters to describe the transformation between the local and the inertial reference frames. The equations of motion are associated with the boundary conditions at each end of the cable to form a nonlinear initial-value two-point boundary-value problem.

Several approaches could be used to solve the equations of motion. One method that is commonly used for this type of problem is the shooting method that can be described as follows. A guess is made for the boundary conditions that are missing at the end of the cable where the integration is started, and the equations of motion are integrated along the cable. The values of the variables at the end of the cable are then compared with the boundary conditions that were prescribed, and the guess of the missing boundary conditions at the starting end is adjusted. The same procedure is repeated until convergence is achieved. Unfortunately, this method does not work well for low-tension cables, so it is not suitable for this research. Instead we use a three-step numerical algorithm based on separate finite differencing in time and in space. First, the nonlinear initial-boundary-value problem is transformed into a nonlinear two-point boundary value problem, using finite differencing (a Newmark-like method) in time. Then, we estimate the values of the different variables along the entire cable at the current time step based on the values at the previous time step. The two-point boundary-value problem is linearized about the estimated solution using a first-order Taylor series expansion. Finally, the two-point boundary-value problem is transformed into an initial-value problem using properties of ordinary linear differential equations. A suppression method is added to prevent divergence of the algorithm. The three steps of this algorithm are repeated until convergence is achieved, at which point time is incremented and the same procedure is repeated. A code using the algorithm is implemented and validated on the example of a towed cable. The objective is to use the code for simulating loop formation in cable payout systems for ocean engineering applications and also to provide the first computational tool for fly fishing equipment.

Hockling (the formation of an interior loop in an otherwise straight cable) is likely to occur in cable payout systems when deploying cables from a surface ship. The cable is spooled, so residual torsion in the cable is unavoidable. At the peel point, the residual torsion has a minor effect on the dynamics of the cable because of the large tensions that develop when the cable is paid out. However, when the cable touches the seabed, the tension is drastically reduced, and torsion becomes significant and can ultimately dictate the dynamics of the cable. This phenomenon must be avoided, because loops usually render the cable inoperable. The dynamics of loop formation are studied on a simple model that does not include payout. The cable is positioned between two supports that move towards each other. The right support remains

stationary, while the left support is moved in a prescribed manner towards the right support, and the two supports ultimately pass by each other. When the cable is simply supported and there is no out-of-plane offset between the two supports, an unstable loop forms as the two ends cross, and it is released by an in-plane instability. When an offset is introduced, the unstable loop is released by a violent out-of-plane instability that dominates the in-plane instability (that still exists). When the supports are cantilevered, the loop formation process is qualitatively different. A loop forms before the two supports have crossed, and it is released when the two supports meet, at which point one turn of twist is introduced in the cable.

In flycasting, two numerical models have been developed to simulate the dynamics of a tapered fly line with an attached fly during a standard overhead cast. First, only the line is modeled, and the motion of the tip of the rod constitutes a boundary condition. The model and numerical algorithm are employed to study the forward stroke of a standard overhead cast. The initial conditions describe a perfectly laid out back cast, from which the forward cast is initiated. Inspection of simulated results reveals three distinct phases of fly line response during the forward cast. These include the nearly rigid body acceleration of the fly line from the back cast, the formation of a loop following the abrupt “stop” of the rod tip, and the propagation and eventual turnover of the loop. The model is further exercised to understand the influence of two sample effects on fly casting, namely the drag created by the attached fly and the shape of the path of the rod tip.

An analytical approximation based on a work-energy balance is developed to model the loop propagation for both a level line and a tapered line. The analytical results are compared with the numerical results. As expected, the agreement is very good during the phase where the loop propagates, but the simplified analytical model fails to accurately predict the loop turnover.

To study the coupling between the dynamics of the fly rod and the fly line, a new numerical model is developed that includes the coupling between the fly rod and the fly line. The dynamics of the fly rod is described using Euler-Bernoulli beam theory, and is then approximated using a one-term Galerkin expansion. In this study, the motion of the hand of the fisherman becomes the boundary condition. The model of the coupled fly rod/fly line is compared to the model of the fly line without the rod. Both models are found to have the same distinct three phases, but they lead to slightly different loop geometries. The geometry of the loop predicted by the coupled model of the fly rod/fly line is compared with experimental data. The shapes are found to agree very well, with only minor discrepancies.